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(54) ALUMINUM ALLOY PISTON EXCELLENT IN HIGH TEMPERATURE FATIGUE STRENGTH AND WEAR RESISTANCE, AND ITS MANUFACTURE

(57)Abstract:

PROBLEM TO BE SOLVED: To provide an aluminum alloy piston exhibiting excellent fatigue strength even in a temperature region as high as 200 to 250°C.

SOLUTION: After forging, this aluminum alloy piston has a composition containing 11-13% Si, 0.2-1.2% Fe, 3.5-4.5% Cu, 0.2-0.5% Mn, 0.3-1.0% Mg, 0.01-0.2% Ti, 0.0002-0.02% B, 0.005-0.02%s P, and Ca in an amount controlled to ≤0.005%. The aluminum alloy piston has a forged structure in which Si and an intermetallic compound both crystallized out at the time of casting are uniformly dispersed, in 5-35 μm average grain size, in a matrix after forging and gas content is controlled to ≤ 0.25 cc/100 g-Al. Further, the average number of inclusions is controlled to ≤0.01 piece/cm2 by K10 value in a stage of an ingot, and forming is performed by forging.

CLAIMS

[Claim(s)]
[Claim 1]After a forge, Si:11-13 % of the weight, Fe:0.2-1.2 % of the weight, Cu:3.5-4.5 % of the weight, Mn:0.2-0.5 % of the weight, Mg:0.3-1.0 % of the weight, Ti:0.01-0.2 % of the weight, B:0.0002 to 0.02 % of the weight, and P:0.005 to 0.02 % of the weight. Regulate an implication and Ca to 0.005 or less % of the weight, and the remainder has the presentation of aluminum substantially, After Si and an intermetallic compound which were crystallized at the time of casting forging, uniform dispersion is carried out to a matrix with mean particle diameter of 5-35 micrometers, A piston made of aluminum alloy excellent in fatigue-at-elevated-temperature intensity and abrasion resistance with a forge organization where gas content was regulated by 0.25cc/100 or less g-aluminum by which the inclusion average number is regulated with K_{10} value in an ingot stage below at 0.01-piece [/cm] ^{2} and which were fabricated by forging.
[Claim 2]After carrying out minuteness making processing of the aluminum alloy molten metal by which quality governing was carried out so that it may become the presentation according to claim 1 after a forge, Blow in applying Ar gas of 0.05-0.20g / 100 g-aluminum to an aluminum alloy molten metal with a molten metal temperature of 750-800 ** for 0.5 to 1.5 hours, and degasifying of the aluminum alloy molten metal is carried out, Hold an aluminum alloy molten metal 45 minutes or more in a 750-800 ** temperature region, and floatation of the inclusion is carried out, After carrying out deslag, carry out continuous casting of the aluminum alloy molten metal to an ingot, and homogenization of 490-510 **x 3 to 5 hours is given, A manufacturing method of a piston made of aluminum alloy excellent in fatigue-at-elevated-temperature intensity and abrasion resistance which are characterized by carrying out forging to specified shape after cooling with a cooling rate at not less than 200 **/o'clock, cutting a cooled ingot to a slice for a forge and heating at 400-500 **.
[Claim 3]A manufacturing method of a piston made of aluminum alloy excellent in fatigue-at-elevated-temperature intensity according to claim 2 and abrasion resistance carrying out water quenching and performing aging treatment of 160-180 **x 6 to 10 hours after performing solution treatment of 490-

510 **x 3 to 5 hours to a forging.

[Claim 4]A manufacturing method of a piston made of aluminum alloy excellent in fatigue-at-elevated-temperature intensity according to claim 2 and abrasion resistance performing aging treatment of 190-200 **x 5 to 7 hours to a forging.

[Translation done.]

DETAILED DESCRIPTION

[Detailed Description of the Invention]
[0001]
[Industrial Application]This invention is used for various internal-combustion engines, and relates to a piston made of aluminum alloy excellent in fatigue-at-elevated-temperature intensity and abrasion resistance, and a manufacturing method for the same.
[0002]
[Conventional technology and a problem] Since lightweight nature is required, as for the engine for vehicle loading represented by the two-wheeled vehicle, the engine made from an aluminum alloy is used. The cylinder case which is an engine part, the piston, etc. are manufacturing the aluminum alloy excellent in high temperature strength and heat resistance by casting, forge, etc. These days, the weight saving of a vehicle and the improvement of fuel consumption are strongly required from a viewpoint of earth environment protection. Therefore, it is lighter-weight also as a piston made of aluminum alloy used for an engine part, and construction material which is more equal to high temperature combustion is desired. When satisfying demand characteristics, promising ** of the piston made from a forge is carried out from thinning or a quality stability field. However, if the piston made from a forge which has come out to the present commercial scene becomes a 200-250 ** pyrosphere, fatigue strength will fall remarkably. In the powder-forging piston using aluminum alloy powder, high temperature strength even with a 200-250 ** sufficient pyrosphere is maintained. However, since a material cost is high as compared with ingot material and a forge moldability is also bad, powder-forging material is not processible into the piston of complicated shape.
[0003]
[Means for Solving the Problem]By thinking out this invention that such a problem should be solved, reducing content gas volume and inclusion which have influence harmful to fatigue-at-elevated-temperature intensity, and carrying out uniform dispersion of the high-melting crystal chance bargain to a matrix so much also systematically, It has the fatigue-at-elevated-temperature intensity which

was excellent also in a 200-250 ** pyrosphere as compared with a conventional material, and aims at obtaining a piston made of aluminum alloy excellent also in forgeability. In order that a piston made of aluminum alloy of this invention may attain the purpose, After a forge, Si:11-13 % of the weight, Fe:0.2-1.2 % of the weight, Cu:3.5-4.5 % of the weight, Mn:0.2-0.5 % of the weight, Mg:0.3-1.0 % of the weight, Ti:0.01-0.2 % of the weight, B:0.0002 to 0.02 % of the weight, and P:0.005 to 0.02 % of the weight. Regulate an implication and Ca to 0.005 or less % of the weight, and the remainder has the presentation of aluminum substantially, After Si and an intermetallic compound which were crystallized at the time of casting forging, uniform dispersion is carried out to a matrix with mean particle diameter of 5-35 micrometers, It has the forge organization where gas content was regulated by 0.25cc/100 or less g-aluminum, the inclusion average number is regulated with K_{10} value in an ingot stage below at 0.01-piece [/cm] ^{2}, and it is fabricated by forging.

[0004]After this piston made of aluminum alloy carries out minuteness making processing of the aluminum alloy molten metal by which quality governing was carried out, Blow in applying Ar gas of 0.05-0.20g / 100 g-aluminum to an aluminum alloy molten metal with a molten metal temperature of 750-800 ** for 0.5 to 1.5 hours, and degasifying of the aluminum alloy molten metal is carried out, Hold an aluminum alloy molten metal 45 minutes or more in a 750-800 ** temperature region, and floatation of the inclusion is carried out, After carrying out deslag, carry out continuous casting of the aluminum alloy molten metal to an ingot, and homogenization of 490-510 **x 3 to 5 hours is given, After cooling with a cooling rate at not less than 200 **/o'clock, cutting a cooled ingot to a slice for a forge and heating at 400-500 **, it is manufactured by carrying out forging to specified shape. Necessary strength is given by deposit of Mg_2Si, aluminum$_2$ Cu, etc., when carrying out water quenching and performing aging treatment of 160-180 **x 6 to 10 hours to a forging, after performing solution treatment of 490-510 **x 3 to 5 hours. Aging treatment of 190-200 **x 5 to 7 hours can also be performed after a forge.

[0005]

[Function]In order to raise the high temperature strength of a piston made of aluminum alloy, it is required to lessen the content gas and inclusion which raise high temperature strength and serve as a core of fatigue breaking. In this invention, high temperature strength is raised by controlling intermetallic compounds crystallized at the time of casting, such as Fe, Cu, and Si, and primary phase Si by forge in moderate size, and carrying out uniform dispersion to a matrix, suppressing softening of the aluminum solid solution of a matrix. Abrasion resistance is improved by controlling primary phase Si in moderate size, and making detailed eutectic crystal Si crystallize as greatly as possible. Hereafter, the monograph affair specified by this invention is explained.

[0006][The ingredient and presentation] after a forge

Si: It is an alloy content effective in 11 to 13-% of the weight abrasion resistance, and heat resistance, and also present the operation which reduces the coefficient of thermal expansion in a pyrosphere.

Again. By aging treatment, it deposits as Mg_2Si and the mechanical strength of the charge of an alloy is raised. However, if a Si content exceeds 13 % of the weight, even if it carries out the cooling rate at the time of continuous casting early in not less than 100 **/second, it will become easy to generate big and rough primary phase Si with the particle diameter of greater than 50 micrometers. It serves as a core of fatigue breaking in order to remain as still big shape also after big and rough primary phase Si is broken by forge, and it becomes the cause of reducing the mechanical strength and fatigue strength in a room temperature and a pyrosphere. However, intensity and abrasion resistance run short in the Si content which is not filled to 11% of the weight.
Fe: The intermetallic compound of an aluminum-Fe system or an aluminum-Fe-Si system with the high 0.2 to 1.2-% of the weight melting point presents the operation which raises tensile strength and fatigue strength when put to the pyrosphere in which the charge of an alloy exceeds 200 **, and an effect becomes remarkable with 0.2 % of the weight or more of Fe contents. However, if a lot of Fe(s) exceeding 1.2 % of the weight are contained, crystallization of the big and rough intermetallic compound used as the core of fatigue breaking will be promoted, and it will be extended, and will have influence harmful to a forge moldability and toughness.
[0007]Cu: It is an alloy content which carries out solid solution strengthening of the matrix 3.5 to 4.5% of the weight, and the addition effect of Cu becomes remarkable by 3.5% of the weight or more of content. Cu which dissolved deposits as aluminum_2 Cu by aging treatment, and also presents the operation which raises the intensity of the charge of an alloy. However, the tensile strength improved effect by Cu is saturated with 4.5 % of the weight. Since hardness is high, it distributes to a matrix and aluminum_2 Cu crystallized at the time of casting raises high temperature strength, but if an excessive amount of Cu(s) exceeding 4.5 % of the weight are contained, it will become easy to crystallize big and rough aluminum_2 Cu used as the core of fatigue breaking, and a forge moldability and corrosion resistance will also fall.
Mn: Crystallize as an aluminum-Mn system compound 0.2 to 0.5% of the weight, and present the operation which improves heat resistance and abrasion resistance. An aluminum-Mn system compound acts on an aluminum-Fe system compound needlelike at the time of crystallization, and a shape change is carried out to the massive compound of an aluminum-Fe-Mn system, and it controls the fall of toughness. Such an operation and an effect become remarkable with 0.2% of the weight or more of a Mn content. However, if an excessive amount of Mn exceeding 0.5 % of the weight is contained, the big and rough compound of an aluminum-Si-Fe-Mn system will crystallize, and it will become the cause of making a crack inducing at the time of plastic working, such as extrusion and a forge, and will lead also to the fall of intensity or elongation. Since a big and rough aluminum-Si-Fe-Mn system compound serves as a core of fatigue breaking, it is harmful also to ordinary temperature and fatigue-at-elevated-temperature intensity.
[0008]Mg: Deposit as Mg_2Si by aging treatment 0.3 to 1.0% of the weight, and raise the mechanical

strength of the charge of an alloy. The improving strength effect is seen with 0.3% of the weight or more of Mg content, and becomes large according to increase in quantity of Mg content. However, if an excessive amount of Mg exceeding 1.0 % of the weight is contained, the fall of elongation will be remarkable and plastic-working nature will also fall.
Ti: In order to carry out minuteness making of the casting crystal grain 0.01 to 0.2% of the weight, it is an alloy content added as an aluminum-Ti-B alloy. The minuteness making effect of cast structure becomes remarkable with 0.01% of the weight or more of a Ti content. By carrying out minuteness making of the casting crystal grain, an intermetallic compound with the high melting point serves as mesh shape, and crystallizes to a grain boundary. It is finely broken by forging which follows, and distributes by it, and the intermetallic compound of mesh shape raises heat resistance and fatigue-at-elevated-temperature intensity. However, if an excessive amount of Ti exceeding 0.2 % of the weight is added, the big and rough needlelike compound of $AlTi_3$ will crystallize, it will be easy to become a core of fatigue breaking, and intensity and elongation will also fall.
[0009]It is an ingredient added by the aluminum alloy molten metal with Ti as a minuteness making agent B:0.0002 to 0.02% of the weight. However, since a lot of B tended to have generated the big and rough intermetallic compound which combines with Ti, V, etc. and serves as a core of fatigue breaking, it set B content as 0.0002 to 0.02% of the weight of the range on balance with the minuteness making effect in this invention.
P: Although it is an ingredient used from the former as a minuteness making agent of primary phase Si added by the hypereutectic alloy beyond 0.005-0.02 % of the weight Si-content 13 % of the weight, the tendency for the particle diameter of eutectic crystal Si to become large by P addition is shown. The minuteness making of primary phase Si becomes remarkable by 0.005% of the weight or more of P content. When various influences of P on the size of primary phase Si and eutectic crystal Si were investigated and studied, in the hypoeutectic presentation of 11 to 13 % of the weight of Si contents, primary phase Si carried out minuteness making by P addition, as a result of eutectic crystal Si's becoming coarse, the particle diameter difference of primary phase Si and eutectic crystal Si became small, and the knowledge of a distribution state also being equalized was carried out. The uniform dispersion of primary phase Si and eutectic crystal Si is effective in the mechanical strength in a pyrosphere, fatigue strength, and abrasion resistance. However, when P content exceeds 0.02 % of the weight, the oxide of P mixes in a molten metal and the tendency which inclusion harmful to fatigue strength increases is shown.
Ca: It is an ingredient which presents the operation which carries out minuteness making of the eutectic crystal Si 0.005 or less % of the weight. By this invention, since eutectic crystal Si is enlarged and it was made to contribute to abrasion resistance, it was prescribed to 0.005% of the weight that the maximum of a Ca content did not affect the minuteness making of eutectic crystal Si. Since the Ca content is reduced, an operation of P which carries out minuteness making of the primary phase Si is revealed effectively.

[0010][Degassing treatment] If a lot of [the piston made of aluminum alloy by which forging was carried out] gas is contained, although the porosity of the gas reason is crushed by the forge, while using it by a 200-250 ** pyrosphere, content gas gathers to a piece place and becomes a core of fatigue cracking easily. When the demand characteristics of the piston made of aluminum alloy used by a pyrosphere were taken into consideration, the experimental result shown in drawing 1 by this invention person etc. showed that 0.25cc/100 or less g-aluminum of gas content were effective. In order to lower gas content, in this invention, degasifying is enough carried out by blowing the Ar gas which does not make a molten aluminum molten metal produce viscosity in a molten metal stage. Since this point and N_2 gas make viscosity of a molten metal high, they are not preferred. It is important to maintain an aluminum alloy molten metal in a 750-800 ** temperature region on the occasion of blowing in of Ar gas. If molten metal temperature is less than 750 **, viscosity will arise in a molten metal and it will become difficult to escape from the blown Ar gas. Conversely, in the molten metal temperature over 800 **, the life of a furnace becomes short. The method which carries out continuation degasifying to the molten metal etc. which flow through the guttering which uses the casting facility provided with the degas unit as degasifying by Ar gas blowing in, for example, results in a metallic mold at the time of casting is also employable. In order to make it distribute in a molten metal by using as detailed air bubbles the Ar gas blown into blowing in of Ar gas, the injection method which uses a rotary nozzle is preferred. The fine bubble of Ar gas adsorbs gas constituents, such as H contained in the molten metal, and floatation is carried out from a molten metal. In order to carry out degasifying of the molten metal effectively, it is required to blow the Ar gas of 0.05-0.20g / 100 g-aluminum over 0.5 to 1.5 hours. Even if the degasifying effect by Ar gas blowing in is insufficient and the amount of Ar gas and blowing-in time exceed a default conversely, the degasifying effect is saturated in the amount of Ar gas and blowing-in time of less than a default.

[0011][Stewing processing] When holding the molten metal which degassing treatment ended 45 minutes or more in a 750-800 ** temperature region, inclusion, such as a protecting agent of $aluminum_2O_3$, other oxides, brick dust, and a tool, carries out floatation from a molten metal. It becomes easy to separate inclusion from a molten metal, so that molten metal temperature is high. In the molten metal temperature below 750 **, the viscosity of a molten metal is large and inclusion cannot surface easily. In the retention time which does not reach in 45 minutes, surfacing of inclusion does not fully advance. However, in the molten metal temperature over 800 **, the heat load of furnace wall refractories is large, and the life of a furnace becomes short. Degasifying and the molten metal by which raking out the slag was carried out are poured into a mold through a guttering with a holding furnace. Degasifying of the molten metal which flows through a guttering is carried out continuously, and a filter device is passed, and also the molten metal to which cleanliness became still higher when carrying out the trap of the inclusion which is floating to the molten metal by weir, a filter cartridge, etc. is poured into a mold, and an ingot with little inclusion is obtained.

[0012][Casting] The defecated molten metal is poured in into a mold and continuous casting is carried

out to the ingot of specified shape. the method which sped up the cooling rate of the molten metal as a casting method in order to make dendrite arm spacing small (preferably 50 micrometers or less) -- DC casting is specifically adopted. DC casting may be any of vertical-type casting or horizontal-type casting. Since the aluminum alloy used by this invention contains Ti and B as a minuteness making agent, it serves as an ingot with a detailed casting crystal grain. However, since cast structure becomes a columnar crystal easily in the alloy composition specified by this invention, it is preferred to make equiaxed grain increase as much as possible by minuteness making processing. Since [that dendrite arm spacing is small] the casting crystal grain is detailed, it distributes finely with mesh shape and intermetallic compounds, such as an aluminum-Fe system with the high melting point, an aluminum-Cu system, an aluminum-Mn system, and an aluminum-Si-Fe (Mn) system, are crystallized on the casting grain boundary and a dendrite arm boundary. Since the crystallized intermetallic compound is broken still more finely at the time of the extrusion of a post process, or a forge and distributes to a matrix, the strength in high temperature of a forging improves.

[0013]Since an ingot is obtained from the aluminum alloy molten metal which reduced inclusion by degasifying and holding processing, its carried-in inclusion has decreased extremely. Usually, it will be blackish and the inclusion intermingled in a forging will be observed, if it has a length of 0.1-3 mm and the fracture surface of an ingot is investigated with a magnifying glass 10 times. Then, this invention person converted the number of the inclusion which observed the fracture surface of the ingot with the magnifying glass 10 times, and counted it per unit area, and calculated K_{10} value. And when the relation between K_{10} value and fatigue strength was investigated and K_{10} value became below 0.01-piece [/cm] ^{2}, it turned out that fatigue strength improves notably. On the other hand, if K_{10} value exceeds 0.01-piece [/cm] ^{2}, inclusion will become a core of fatigue cracking easily and the fatigue-at-elevated-temperature intensity required of a piston will not be obtained. The round bar of a byway is made from an ingot through an extrusion process, and the slice started from the round bar is forged. In this case, consideration of the shape of the piston which is the last gestalt will use an ingot 100-400 mm in diameter. Or after removing the scale on the surface of an ingot by facing, it is also possible to start and forge a slice from an ingot, without passing through an extrusion process. In this case, an ingot 50-100 mm in diameter is used.

[0014][Homogenization] In order that the obtained ingot may make Si, Mg, and Cu dissolve enough to a matrix and may raise aging treatment hardening, it is homogenized in 490-510**x3 - 5 hours. In the cooking time which does not reach in the cooking temperature below 490 **, or 3 hours, dissolution-ization does not fully tend to advance but effective doses, such as Si, Mg, and Cu, tend to be insufficient at the time of aging treatment. However, there is a possibility of dissolving selectively in the cooking temperature over 510 ** (burning), the rise of the effect which balanced time in prolonged heating exceeding 5 hours is not seen, and it is not economical. The homogenized ingot is cooled with the cooling rate at not less than 200 **/o'clock. Sufficient quantity of Si, Mg, and Cu is maintained

by the dissolution state by this, and a precipitation amount effective in intensity grant at the time of aging treatment is secured. When a cooling rate is less than o'clock in 200 ** /, Mg_2Si, $aluminum_2$ Cu, etc. deposit easily by a cooling process, and effective doses, such as Si, Mg, and Cu, tend to be insufficient at the time of aging treatment.

[0015][Forge] After the ingot which is 100-400 mm in diameter which homogenization ended is cut by the billet for extrusion and extruded by the round bar for a forge, it is started by the predetermined slice. In an ingot 50-100 mm in diameter, after facing removes the scale on the surface of an ingot, without passing through an extrusion process, it is started by the slice for a forge. It is also possible to use for a forge the slice started from the ingot, without removing a scale. In this case, use of the metallic mold (JP,10-118735,A) which provided the metal **** part between the inner surface of a female die parallel to a forging direction and the punch part outside surface of a male will prevent mixing of the scale to a forging. In advance of a forge, hot forging of the slice for a forge is heated and carried out to 400-500 **. When heating the slice for a forge in a 400-500 ** temperature region, a smooth flow of a metal is promoted within a forging metal mold, and the pressure at the time of a forge is also small as compared with cold forging, and it ends.

[0016]The heated slice for a forge is set to a forging metal mold, and forging is carried out to specified shape. Material is elaborated with a forge and toughness is given to a product. Since mesh shape crystallized material generated at the time of casting, such as primary phase Si and an intermetallic compound, is finely broken by forge and distributes to a matrix, heat resistance improves. Especially, since crystallized material, such as primary phase Si used as the core of fatigue breaking, will be lost if primary phase Si and an intermetallic compound are crushed in mean particle diameter of 5-35 micrometers with a forge and uniform dispersion is carried out to a matrix, ordinary temperature and fatigue-at-elevated-temperature intensity are improved. If the crystallized material exceeding the mean particle diameter of 35 micrometers is distributed over the organization after a forge, it will be easy to become a core of fatigue cracking. It is also effective in a wear-resistant improvement that big primary phase Si is broken with a forge by the size which is the mean particle diameter of 5-35 micrometers. Both the reverse extrusion which pushes a mandrel against the fixed slice as a forge method, and makes a metal flow along with a mandrel, and the forward extrusion which forces a slice on the fixed mandrel and makes a metal flow along with a mandrel are employable.

[0017][Heat treatment] In order that a forging may give the mechanical properties demanded as a piston, after performing 490-510**x3 - solution treatment of 5 hours, water quenching is carried out and aging treatment of 160-180**x6 - the ten hours is carried out. Mg, Si, Cu, etc. are made to dissolve enough to a matrix in solution treatment. Dissolution states, such as Mg, Si, and Cu, are maintained to ordinary temperature with water quenching, by aging treatment, it is made to deposit as Mg_2Si, $aluminum_2$ Cu, etc., and predetermined intensity is given. Aging treatment of 190-200 **x 5 to 7 hours can be performed without carrying out solution treatment for the prevention from a dimensional change of a forging, and intensity can also be given. A required part is machined and a

product piston is made to the forging by which aging treatment was carried out.
[0018]
[Example]The aluminum alloy molten metal which carried out quality governing to prescribed composition was maintained at 770 **, from the rotary nozzle which immersed in the molten metal, the Ar gas of 0.1g / 100 g-aluminum was made to inject for 40 minutes, and degasifying was carried out. Subsequently, after holding the molten metal for 60 minutes at 760 ** and carrying out floatation of the inclusion, vertical-type DC casting was carried out at an ingot 86 mm in diameter, and 5 m in length. Homogenization of 500 **x 4 hours was given to the ingot, and the air cooling with blower was carried out with the fan with the cooling rate at 250 **/o'clock. 2-mm facing of the ingot surface after cooling in thickness was carried out, and the slice for a forge 21 mm in length was started. The slice 1 for a forge was set in the forging apparatus of the reverse extrusion method showing an outline in drawing 2. In advance of the forge, the slice 1 for a forge was heated at 460 **, and the bottom part 2 and the metallic mold 3 provided with punch were heated at 200-250 **. The mandrel 4 was stuffed into the slice 1 for a forge on the bottom part 2 from the upper part, and the welding pressure of 350 t was applied to the slice 1 for a forge. The tip of the mandrel 4 ate into the slice 1 for a forge, and as a metal showed by the arrow F, along with the mandrel 4, it flowed up. After dropping the mandrel 4 to a prescribed position, while drawing out the mandrel 4, the punch built in the bottom part 2 was raised, and the forging with 84 mm in diameter and 47-mm-high piston shape was picked out from the metallic mold 3. Upsetting **** at this time was 76% in the head section.
[0019]Water quenching of the solution treatment of 500 **x 4 hours was performed and carried out to the forging, and aging treatment was carried out in 170 **x 8 hours. Observed the organization after aging treatment, and gas content was measured, and mechanical properties were investigated. Gas content started the sample from the forging after aging treatment, and measured it by the run ZURE method. Since the forging was fractured with the hammer and it ran away about inclusion, the slice started from the cast bar was broken with the hammer, the fracture surface was observed with the magnifying glass 10 times, the number of inclusion was counted, and K_{10} value was calculated. The observed face product was taken as both 20 cm in all of fracture surface ^{2}. The presentation of the obtained piston is shown in Table 1. The comparison alloys A and B are the examples which did not carry out minuteness making of the primary phase Si by P among front, and the comparison alloy A carried out minuteness making of the eutectic crystal Si by Sb before long. As a result of observing a microstructure after aging treatment, gas content is shown in Table 2. The measurement result of tensile strength and fatigue strength is shown in Table 3.
[0020]Compared with the comparison article A and B, the tensile strength and fatigue strength in the elevated temperature of this invention article C-F are large so that clearly from Table 3. Although the comparison article A had the presentation equivalent to the present forged piston, since minuteness making of the primary phase Si had not been carried out by P, as the mean particle diameter of primary phase Si showed in Table 2, it was large, and since minuteness making of the eutectic crystal

Si was carried out by Sb, it was small. As a result, big primary phase Si serves as a core of fatigue cracking, and acts, and it is guessed that brought a result of Table 3 in which fatigue-at-elevated-temperature intensity is inferior, and it appeared. And since there is little content of Cu and Fe, as compared with this invention article, high temperature strength is inferior in the comparison article A. Since there is little content of Cu, Mn, and Ti, the comparison article B shows the value with low high temperature strength which has little quantity of a high-melting crystal chance bargain. And since there was extremely little Cu, fatigue strength was also inferior in primary phase Si few small [the gap from an eutectic point] therefore. On the other hand, this invention article C-G showed tensile strength and fatigue strength outstanding also in ordinary temperature and hot any. When checking these mechanical properties with the crystallized material measurement result of Table 2, it turns out that it is effective in a mechanical strength, fatigue strength, and heat-resistant improvement to control primary phase Si, eutectic crystal Si, and the intermetallic compound after a forge to the proper size.

[0021]

表１：製造されたアルミニウム合金製ピストンの成分・組成

試料記号	合金成分及び含有量 (重量%)									区分
	Ｓｉ	Ｆｅ	Ｃｕ	Ｍｎ	Ｍｇ	Ｔｉ	Ｂ	Ｓｂ	Ｐ	
A	10.5	0.18	3.0	0.7	0.5	0.1	0.0070	0.15	0	比較例
B	11.2	0.21	0.9	0.0	1.0	0.0	0.0050	0	0	比較例
C	11.1	0.22	3.5	0.3	0.5	0.1	0.0020	0	0.0065	本発明例
D	12.5	0.41	4.1	0.2	0.8	0.2	0.0041	0	0.0082	本発明例
E	11.7	0.35	4.0	0.2	0.8	0.2	0.0037	0	0.0098	本発明例
F	12.1	0.83	4.5	0.3	0.8	0.1	0.0025	0	0.0085	本発明例
G	11.9	0.82	4.5	0.5	0.9	0.2	0.0041	0	0.0093	本発明例

[0022]

表２：時効処理されたアルミニウム合金製ピストンのミクロ組織

試料記号	晶出物の平均粒径 (μm)		ガス含有量 (cc/100g－Ａｌ)	K_{10}値	区分
	初晶Ｓｉ	共晶Ｓｉ及び他の金属間化合物			
A	120	3.8	0.19	0.004	比較例
B	18	4.2	0.20	0.005	比較例
C	30	6.2	0.15	0.005	本発明例
D	28	5.8	0.19	0.002	本発明例
E	29	6.3	0.21	0.006	本発明例
F	27	6.2	0.22	0.003	本発明例
G	29	5.7	0.18	0.001	本発明例

[0023]
表３：時効処理されたアルミニウム合金製ピストンの機械的特性

試料記号	引張強さ（ＭＰａ）				疲労強度（ＭＰａ）				区分
	室温	150℃	200℃	250℃	室温	150℃	200℃	250℃	
A	471	343	196	98	165	137	96	62	比較例
B	382	275	206	88	154	129	91	60	
C	481	373	216	95	168	139	107	67	本発明例
D	476	403	270	115	167	139	108	67	
E	483	409	272	117	169	140	109	68	
F	482	407	271	114	168	139	108	68	
G	485	408	273	117	169	141	109	69	

疲労強度は、１０^{7}サイクルの値で示す。

[0024]Subsequently, after carrying out degasifying of the aluminum alloy molten metal with the presentation D of Table 1, holding processing was carried out to 720 ** and a comparatively low temperature in a short time for 15 minutes, and others manufactured the piston under the same conditions. Although the obtained piston had little gas content as 0.20 cc / 100 g-aluminum, there was much inclusion number at K_{10} value as 0.25-piece [/cm] ^{2}. Fatigue-at-elevated-temperature intensity showed 56MPa (10 ^{7} cycle) and a low value at 250 **. Low fatigue-at-elevated-temperature intensity is imagined to be the result on which a lot of inclusion acted as a core of fatigue cracking.

[0025]Degasifying of the aluminum alloy molten metal with the presentation E of Table 1 was carried out at 760 ** for 15 minutes, by the request, inclusion was removed under the same conditions as this invention article, and the piston was manufactured. There was much gas content of the obtained piston as 0.35 cc / 100 g-aluminum, and the inclusion number showed K_{10}= 0.003-piece [/cm] ^{2} and a small value. Fatigue-at-elevated-temperature intensity showed 59MPa (10 ^{7} cycle) and a low value at 250 **. Low fatigue-at-elevated-temperature intensity is imagined to have a cause in a lot of gas contained at the piston. When the abrasion resistance of each piston was investigated, as shown in Table 4, this invention article C-G showed abrasion resistance better than the comparison article A and B, though the conventional comparison article A and B and Si content were the same level. Although this has eutectic crystal Si of the comparison article A and B as small as the mean particle diameter of 3.8 micrometers, and 4.2 micrometers, since it enlarges the particle diameter of eutectic crystal Si by P processing and contains comparatively a lot of Fe(s) and Cu(s), it is imagined to be what the crystallized material of the eutectic crystals Si and Fe and a Cu system has contributed to wear-resistant improvement by this invention article C-G.

[0026]

表４：各合金から鍛造で作られたピストンの耐摩耗性

区分	試料記号	比摩耗量 ($\times 10^{-7} mm^2/kg$)
比較合金	A	7.95
	B	9.94
本発明合金	C	6.08
	D	6.23
	E	6.12
	F	6.11
	G	6.14

（試験条件）
試験機：大越式，　摩耗子：ＦＣ３０
荷重：２．１ｋｇ，　回転速度：１．２ｍ／秒
回転距離：６００ｍ

[0027]

[Effect of the Invention]As explained above, in the system as which the ingredient and the presentation were specified, the piston made of aluminum alloy of this invention is made the forge organization which controlled and did uniform dispersion of primary phase Si, eutectic crystal Si, and the intermetallic compound which were crystallized at the time of casting to the proper size, and it is stopping gas content and the inclusion number low. It is used as a piston for engines in the tendency for this to show a mechanical strength and fatigue strength excellent in ordinary temperature and an elevated temperature, and to harness lightweight nature, and for heat load to become large.

[Translation done.]